Omega-3 Fatty Acids in Hawaii Seafood

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Omega-3 fatty acids, the most potent of which are found in seafood, are of interest because of their effects on cardiovascular and inflammatory diseases and their possible effects on cancer. However, consumers in Hawaii wishing to increase their dietary omega-3 to omega-6 fatty acid ratio are faced with the difficulty that several types of seafood popular in Hawaii and aquacultured seafood new in the marketplace have unknown omega-3 fatty acid levels. The purpose of this work is to determine omega-3 fatty acid levels of selected seafood and fish oil capsules. Several seafoods and some over-the-counter fish oil capsules were sampled and analyzed. Aku eggs, aquacultured hamachi (yellowtail jack from Japan), one sample of turbot, and EPA Plus, Promega, and Omega-3 Super EPA capsules were found to contain high levels of omega-3 fatty acids. Levels were comparable to those in the fatty fishes such as salmon and mackerel. Butterfish, mahimahi eggs; other fish oil capsules (ProEPA and Omega 3) contained moderate levels of omega-3 fatty acids. Fish cakes, seaweed, several lean fishes, and cod liver oil capsules had small quantities of omega-3 fatty acids. It appeared that the omega-3 fatty acid content of aquacultured species studied was significantly higher than in wild caught species. There was a substantial difference between claimed and actual omega-3 fatty acid levels in commercially available fish oil capsules. These findings can help consumers when selecting types of seafood for their diet that are good sources of omega-3 fatty acids.

Introduction

Greenland Eskimos have a very low incidence of cardiovascular disease as compared to the Western population.[1,2] A study of Caucasian Americans, Japanese Americans, urban Japanese, and rural Japanese showed increasing levels of fish consumption.[3] This was correlated with decreasing incidence of death due to heart disease.[4] Another study from Japan compared fishing villagers with farming villagers.[5] Fishing villagers consumed approximately 3 times more seafood than farming villagers. Cardiovascular disease among fishing villagers was almost half that of farming villagers. People who live on the shores of the Mediterranean Sea also have a low incidence of cardiovascular disease.[6] It has been argued that the longevity of the Japanese is because of their low fat diet. However, the Greenland Eskimos who consume large amounts of marine mammal blubber do not have a low fat diet and the diet of the Mediterranean people is as high in fat as the American diet. A common feature of the diets of Eskimos, Japanese, and Mediterranean people is the high omega-3 to omega-6 dietary fatty acid ratio because of the high consumption of seafood and the low consumption of oils from oil seeds, a rich source of omega-6 fatty acids.

All fats are equally calorie dense; however, different fats are made up of different fatty acids. The solid fats such as lard or butter are relatively rich in saturated fatty acids. When eaten in excess they are associated with elevated mortality rates from cardiovascular disease and cancer.[6] Some culinary oils such as olive or macadamia nut oil contain high levels of mono-unsaturated fatty acids.[7] Mono-unsaturated fatty acid oils are known for their healthfulness.[8] Seafood is rich in omega-3 fatty acids and some plant seed oils are rich in omega-6 fatty acids.

Omega-3 and omega-6 fatty acids are polyunsaturated fatty acids differentiated by the position of their first double bond. In omega-3 fatty acids, the first double bond occurs at the third carbon from the methyl end of the fatty acid. In omega-6 fatty acids, the first double bond is located at the sixth carbon from the methyl end of the molecule. Omega-3 and omega-6 fatty acids are biochemical competitors[9] that compete with each other in elongation from C18 precursors to C20 and C22 end products and incorporation into tissue lipids. Unlike other nutrients, body membrane compositions tend to mirror the fatty acids in the diet. Even skin fatty acids reflect diet[10]: The eicosanoids (prostaglandins and leukotrienes) synthesized from these tissue lipids have different effects depending on whether they were derived from omega-3 or omega-6 highly unsaturated fatty acids.[11]

In the following, the marine highly unsaturated fatty acids eicosapentaenoic acid, 20:5n-3 (EPA) and docosahexaenoic acid, 22:6n-3 (DHA) will be discussed. DHA and EPA are many times more physiologically active than linolenic acid (18:3n-3), their precursor from plant chloroplasts in terrestrial species.[12] Omega-3 fatty acids prevent atherosclerosis in hyperlipidemic pigs,[13] delay early restenosis,[14,15,16] and alleviate the symptoms of rheumatoid arthritis.[17,18,19] Evidence is beginning to accumulate that fish oil containing EPA and DHA inhibits tumor initiation and growth in comparison to an oil containing omega-6 fatty acids.[20] DHA is required for the development of intelligence in rats and for the development of vision in human infants.[21,22] It is considered desirable to provide DHA to premature infants since DHA is laid down in the last trimester of pregnancy and

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metabolic conversion of precursors to DHA is probably insufficient to meet infants' needs. Finally, it is becoming clear that DHA is required for stress resistance in fish.[23,24] DHA reduces stress mortality in rats injected daily with isoproterenol[25] suggesting that DHA might be important for stress resistance in terrestrial species.

The purpose of this study was to determine omega-3 fatty acid levels in Hawaii seafood. Many of these seafood and fish oil capsules were of unknown omega-3 fatty acid content. It will be shown that there are several excellent sources of omega-3 fatty acids in Hawaii.

Methods

Sampling.—Fish oil capsules were purchased from discount drugstores; 3 different brands of nori (*Porphyra* spp.) and single samples of the fish cakes and ogo (*Gracillaria* spp.) were purchased from supermarkets. It was expected there would be significant biological variation in some samples; hence, they were analyzed in replicate. Aku (*Katsuwonus pelamis*) and mahimahi eggs (*Coryphaena hippurus*) are actually egg-filled ovaries. Three samples of each were obtained from the local fish auction (United Fishing Agency, Inc.) and they can be purchased at seafood specialty stores in season. Four samples of hamachi (yellowtail jack, *Seriola quinqueradiata*) and 3 samples each of turbot (*Scophthalmus maximus L.*) and butterfish (*Peprilus triacanthus*) were purchased from the seafood sections of local supermarkets. Cultured mahimahi samples were obtained from a research project of the University of Hawaii and the Waikiki Aquarium. Tissue samples from 3 wild caught mahimahi were obtained from the Anuenue Fisheries Research Center.

Chemical analysis:—Wet samples were freeze-dried and pulverized using a coffee grinder. These and the nori samples were extracted according to a method developed in our laboratory.[26] Extraction occurred in a Soxhlet's apparatus with chloroform/methanol (2:1). BF_3/methanol reagent was used to methylate saponified fatty acids. Fatty acid methyl esters were quantified by gas chromatography on an HP-5840A gas chromatograph containing a Restek Stabilwax megabore column.

In all cases, the C17 fatty acid heptadecanoate was added to the original sample as an internal standard and recovery of this fatty acid was measured. Results were corrected for incomplete recovery of heptadecanoate. Analyses with recoveries <67% were rejected and analyses were repeated.

For fish samples, data are reported in terms of 100 g portions that would be eaten (not on a dry-weight basis).

Results

Table 1 shows the claimed and actual values of omega-3 fatty acids in 2 groups of fish oil capsules, the newer, *enriched* fish oil capsules and the cod liver oil capsules. The omega-3 level was calculated by adding together EPA and DHA values. Four out of 5 enriched fish oil capsules claimed 180 mg EPA and 120 mg DHA per capsule for an omega-3 fatty acid level of 300 mg per capsule. As shown in Table 1, EPA Plus and Omega-3 Super EPA contained slightly more omega-3 fatty acids than claimed, while the other capsules contained substantially lower levels of omega-3 fatty acids than claimed. Cod liver oil capsules contained lower levels of omega-3 fatty acids than the enriched fish oil capsules.

Table 1.—Omega-3 Fatty Acid Levels in Fish Oil Capsules (g per capsule)

	Omega-3 Claimed	Actual	Daily Dose Recommended
EPA Plus	0.300	0.305	3-6
Promega	0.307	0.196	6-9
Omega-3/ Super EPA	0.300	0.333	3
ProEPA	0.300	0.143	3-6
Omega 3	0.300	0.097	3-6
Cod liver	0.070	0.150	2
Norwegian cod liver	0.067-0.083	0.040	1-6

Table 2 shows some results of replicated analyses of several types of seafood. Visual inspection suggested that amounts of omega-3 fatty acids among the fish ovaries might vary; within species, some ovaries contained loose eggs as if the female was ready to spawn. Other ovaries contained small, attached eggs. The results, however, showed very little difference among samples. Mahimahi ovary No. 1 was from an aquacultured female. Its omega-3 fatty acid content did not appear to differ substantially from ovaries from wild caught mahimahi. Although hamachi and turbot samples were all purchased at the same store and were packaged identically, there was a wide variation in omega-3 fatty acid levels in both groups of fish. The range of omega-3 fatty acids in the hamachi group was between 0.96 and 6.15 g per 100 g sample and the range among turbot samples was between 0.19 and 2.22 g per 100 g sample.

Table 3 summarizes omega-3 fatty acid and total fatty acids among the samples analyzed in this work and from the literature.[27] Maximal daily recommended doses of fish oil capsules were used in the summaries. Samples were arranged in order of decreasing omega-3 fatty acid level.

Discussion

Our purpose in this study was to analyze omega-3 fatty acids in selected seafood and fish oil capsules available in Hawaii; the tables could be used as a consumer rating list. However, there appear to be some simplifications.

The cold-water, fatty fishes known for their high omega-3 fatty acid content include sardines and salmon. Traditional knowledge holds that cold-water fish are fatty because low water temperature requires highly unsaturated, omega-3 fatty acids to maintain membrane fluidity. Aquaculture provides an alternate explanation. Highly efficient, cold-water carnivores are fatty possibly because they live in waters containing abundant prey. Highly efficient tropical carnivores such as mahimahi or ahi live in relatively barren waters, expend vast amounts of

Table 2.—Variations in Fatty Acid Levels among Replicated Seafood
(g/100 g portion)

	Total Fatty Acids	Omega-6	Omega-3
Aku ovary 1	2.88	0.26	1.40
Aku ovary 2	3.66	0.20	1.85
Aku ovary 3	3.98	0.17	1.73
Average	3.51±0.46	0.21±0.04	1.66±0.19
Mahimahi ovary 1	1.54	0.05	0.77
Mahimahi ovary 2	1.35	0.03	0.58
Mahimahi ovary 3	1.34	0.06	0.56
Average	1.41±0.09	0.05±0.01	0.64±0.09
Hamachi 1	9.88	0.50	4.32
Hamachi 2	13.50	0.65	6.15
Hamachi 3	8.69	0.58	2.33
Hamachi 4	3.54	0.26	0.96
Average	8.91±3.57	0.50±0.15	3.44+1.97
Turbot 1*	7.05	0.14	2.22
Turbot 2	0.41	0.03	0.19
Turbot 3	0.42	0.03	0.20

*Average of duplicate extractions

Table 3.—Omega-3 Fatty Acids in Selected Seafood

	Omega-3	Total Fatty Acids
Hamachi	3.44±1.97	8.90±3.57
Turbot 1	2.22	7.05
Sardines, canned, tomato sauce[26]	1.94	12.0
EPA Plus	1.83	4.27
Salmon, canned pink[26]	1.83	6.05
Promega	1.76	3.15
Salmon, Chinook (king)[26]	1.71	10.4
Aku ovary	1.66±0.19	3.51±0.46
Mahimahi, aquacultured	1.34±0.11	5.76±0.71
Omega-3 Super EPA	1.00	2.20
ProEPA	0.86	2.22
Ulua[26]	0.77	9.47
Tuna, white canned in water[26]	0.76	2.6
Mahimahi ovary	0.64±0.09	1.41±0.09
Omega 3	0.58	1.62
Butterfish	0.57±0.03	4.75±0.12
Shrimps[26]	0.53	1.73
Snapper (eg, opakapaka)[26]	0.39	1.34
Mahimahi, frozen	0.34±0.02	1.46±0.37
Cod liver oil	0.30	0.72
Norwegian cod liver	0.24	0.78
Tuna, yellowfin (ahi)[26]	0.24	0.95
Mahimahi, wild, Hawaii	0.21±0.01	0.57±0.03
Turbot 2 and 3	0.20	0.42
Chikuwa (broiled)	0.11	0.24
Nori	0.096±0.04	0.22±0.09
Tempura (fried)	0.09	1.65
Kamaboko	0.04	0.10
Ogo	0.04	0.52

*g per 100 g portion or daily dose

energy while hunting, are not able to deposit much fat, and are therefore low in omega-3 fatty acids. Hamachi are aquacultured in Japan where approximately 160,000 tons of hamachi are cultivated annually.[28] Hamachi is a member of the jack family and like ulua (Table 3) should contain moderate amounts of tissue omega-3 fatty acids. When omega-3 fatty acid values for replicated hamachi samples were averaged, hamachi had the highest omega-3 level of all seafood.

Turbot samplings provided a different look at the effect of aquaculture on omega-3 fatty acid levels. Turbot is a lean fish and should belong to a low omega-3 group; samples 2 and 3 fell in the low omega-3 fatty acid group. However, turbot sample 1 had an omega-3 fatty acid value of 2.22 g/100 g portion, placing it among the richest sources of omega-3 fatty acids. We speculate that turbot samplings were a mixture of aquacultured and wild caught fish.

Such speculation is not necessary for mahimahi. A substantial difference in mean omega-3 fatty acid levels was seen between mahimahi caught at sea (0.21 g/100 g portion) and those aquacultured (1.34 g/100 g). The latter would be a good source of omega-3 fatty acids; the former exhibits the fatty acid profile of a very lean fish. It has been stated that aquacultured fish are poorer in omega-3 fatty acids than wild caught fish.[29] Mahimahi aquaculture (in the first author's laboratory) suggests that this does not have to be the case. It demonstrates that food can be designed for specific nutritional purposes, in this case high DHA content.

Fish ovaries or *eggs* seem to be a good source of omega-3 fatty acids. This may be an example of folklore having a scientific basis. Female fish with ripe ovaries are sold at a premium in the Far and Middle East. Presentation of fish heads to the most esteemed members of oriental families is also folklore having a scientific basis. Visual and neural tissues are high in DHA.

The best of the newer enriched fish oil capsules also are high in omega-3 fatty acids. All of the enriched fish oil capsules contained more omega-3 fatty acids than cod liver oil capsules. The 2 cod liver oils tested low in omega-3 fatty acid level which could relate to the toxic effect of high concentrations of fat soluble vitamins in cod liver oils. Dose levels of cod liver oils should be limited to avoid vitamin A overdose. Probably because of this factor, newer sources of fish oil for capsules, less destructive processing methods, and more efficacious storage methods are responsible for higher omega-3 fatty acid levels in the newer fish oil capsules. Two samples (EPA Plus and Omega-3 Super EPA) were sold in amber bottles to prevent light damage and came sealed to prevent oxidation of fatty acids.

Seaweed and fish cakes were low in omega-3 fatty acids which is not surprising because sea plants are low in fat and fish cakes are prepared from lean fish such as awa (milk fish) or pollock.

Are any of the seafood or fish oil capsules a panacea? The answer to this question is no. Most of the seafood is very low in fatty acids. They could be used in weight loss programs and to decrease dietary fat intake while providing high quality dietary protein. However, other sources of energy must be minimized. Seafood is low in saturated fatty acids which are a risk factor[6] and could be used to lower dietary saturated fatty acids if other

sources of saturated fatty acids also are minimized. A steak and lobster dinner with butter is an example of a mixed-effect meal. Some functions such as the development of vision in premature infants seem to require DHA.[21] But other positive health benefits of omega-3 fatty acids are probably more concerned with the dietary omega-3 to omega-6 ratio. The seafood richest in omega-3 fatty acids probably offers the best hope of changing the dietary omega-3 to omega-6 ratio; a significant change in the ratio requires lowering the omega-6 fatty acid intake. This is one reason why the Mediterranean diet is interesting. After Japan, Spain consumes more seafood per capita than any other country. The Mediterranean diet uses olive oil, a culinary oil low in the omega-6 fatty acid, linoleate (18:2n-6). A Hawaii equivalent would be aquacultured mahimahi cooked or marinated in macadamia nut oil which is almost linoleate free.

The omega-3 to omega-6 ratio concept also illustrates the difficulty of using the fish oil capsules. Adding omega-3 fatty acids to a diet high in omega-6 fatty acids would probably not do much good although numerous controlled studies have shown that fish or fish oil capsules can alter the body's omega-3 to omega-6 fatty acid ratio. Simopoulos[9] reviewed the increase of omega-6 fatty acids in people's diets worldwide and he also reviewed the anthropological data suggesting that humans evolved with a dietary omega-3 to omega-6 ratio of about one-to-one.

According to National Marine Fisheries studies, seafood consumption in Hawaii is substantially higher than on the Mainland. Perhaps some people in Hawaii have less of an aversion to seafood than people on the mainland U.S. This may be related to differences in death rate due to heart disease between Mainland and Hawaii people. The difference is substantial. According to Brian Horiuchi (Hawaii Department of Health) deaths from heart disease in Hawaii were 185.9 per 100,000 in 1987. In the same period, the death rate due to heart disease on the Mainland was 313.4 per 100,000. The difference in mortality could be due to seafood consumption but it is probably not by lowering of blood cholesterol levels. Eating seafood does not have a substantial effect on blood cholesterol levels.[30]

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